THE PRODUCTION OF JETS FROM MAGNETIZED ACCRETION DISKS: SIMULATION OF THE BLANDFORD-PAYNE MECHANISM

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Abstract. We have used massively parallel supercomputer simulations to perform an extensive study of a plausible mechanism for producing the jets seen in extragalactic radio sources -- acceleration and collimation by coronal magnetic fields in an accretion disk orbiting a central black hole. We find that such disks can propel jets for a wide range of coronal conditions. The terminal jet velocity is a strong function of the magnetic field equatorial component. Acceleration and collimation are produced by a tight azimuthal field coil generated in the corona, rather than by a stiff poloidal field extending to large distances. The jets are pressure-confined when the external medium pressure is high, but magnetically-confined when it is low.

Blandford and Payne (1982, *M.N.R.A.S.*, 199, 883) suggested that strong magnetic fields in a differentially-rotating accretion disk might be responsible for generating the jets seen in extragalactic radio sources. In their steady-state, self-similar model magnetic field lines are anchored in a dense, infinitely-thin disk, with the poloidal component of the field making an angle $\theta > 30°$ with the rotation (z) axis. Above the disk is a warm corona, expanding sub-magnetosonically along the field lines. Two jet mechanisms are possible: (1) for sufficient field strength, centrifugal action flings coronal material outward and upward along field lines and differential rotation winds up B_ϕ to virial values, causing magnetic tension $(B_\phi^2/4\pi r)$ to squeeze and collimate the outflow; (2) B_ϕ winds up to virial values on a few dynamical times, producing a magnetic pressure explosion $(d(B_\phi^2/8\pi)/dr)$ and pushing material upward (Shibata and Uchida 1985, *P.A.S.J.*, 37, 31).

We have studied magnetized disks under more realistic (non-steady-state, non-self-similar) conditions using our non-relativistic, 2-D axisym-

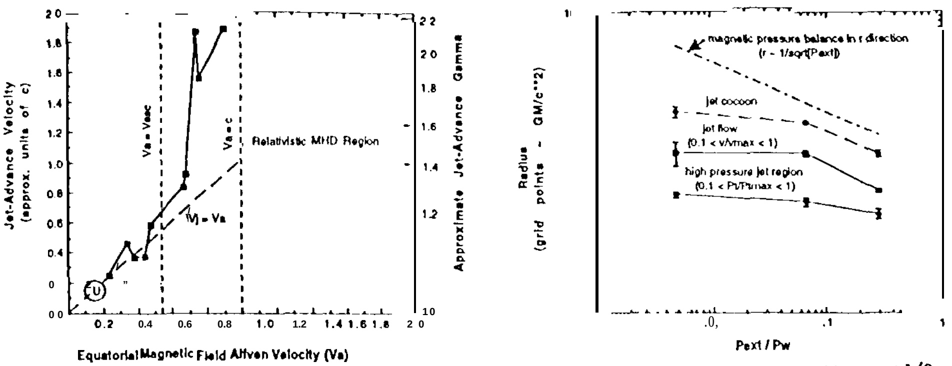

Figure 1. (a) Jet advance speed *vs.* equatorial Alfvén velocity ($V_a = B_{eq}/(4\pi\rho_w)^{1/2}$) for 10 of our models plus that from Ustyugova *et al.* (1995, *Ap. J.*, 439, 1,39) (the circle-U point); (b) jet./cocoon radii *vs.* external ambient medium pressure.

metric, magnetohydrodynamic simulation code (Lind, Payne, Meier, and Blandford 1989, *Ap.J.*, *344, 89).* The disk, field, and coronal wind are imposed as initial/boundary conditions along the disk equator, and the flow evolution above the disk is computed. We performed a limited parameter study by varying the disk field $(0.5 \leq V_a \leq 2)$, poloidal field pitch θ, and external pressure $(0.005 \leq P_{ext}/P_w \leq 0.28)$. For all simulations the fixed parameters were: $V_\phi = V_K$ (Keplerian velocity), $c_s = 0.76 V_K$, $V_w = 0.07 V_K$, and $\rho_{ext} = 0.05 \rho_w$. Our 15 simulations had moderate resolution (150 radial x 300 axial cells), were evolved for $\sim$ 3 inner disk rotation times, and used $\sim$ 12 hours on the Caltech/JPL Intel Touchstone Delta massively parallel supercomputer (the equivalent of $\sim$ 2 weeks of Cray Y-MP time).

We find collimated outflow in all our models and that the magnetic explosion mechanism obtains in this region of parameter space. (For more details see Meier, Payne, and Lind 1996, in preparation.) For models with the same P_{ext}, but a variety of magnetic field conditions, the jet advance speed appears to be a function of a single parameter – the equatorial magnetic field ($B_{eq} = (B_r^2 + B_\phi^2)^{1/2}$; see figure 1 a). For low values of B_{eq} the jet speed remains close to the Alfvén speed, but when V_a exceeds the escape velocity significant jet outflow velocities can occur. While strictly non-relativistic, the model flow velocity can be identified as the spatial component of the 4-velocity (ΓV), if jet thermal and magnetic inertia is small. Our jets reach $\Gamma \sim 2$, but Γ could be much higher for relativistic MHD calculations.

Figure 1 b shows the extent of various radial zones in the jet – high pressure core, jet flow, and cocoon – as a function of external pressure, and compares with the trend expected for pure pressure confinement. For external pressures comparable to the coronal pressure the cocoon and jet flow appear to be pressure-confined. But for low external pressures, magnetic stresses provide the confinement. Note that there is always a small magnetically-confined core along the jet axis for all values of P_{ext} studied.